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To F.J. Kee
Director of Research

DEHUMIDIFICATION HEAT PUMP WOOD DRYER - PERFORMANCE EVALUATION

J.B. Ciz

A heat pump wood drying kiln located in Listowel, Ontario was instrumented and monitored between September 10, 1982 and March 14, 1983. The results of the field experiment show that heat pump dehumidification technology works and will save energy. One of the monitored drying cycles, considered to be typical, saved 60% of the energy required for a comparable fossil-fueled kiln. Recommendations are made for further work to promote this technology.

1.0 INTRODUCTION

Traditionally, kiln dried wood has been processed using the "Heat and Vent" method shown schematically in Figure 1. Heat from combustion-fired boilers is used to drive moisture from the wood, and the resulting hot humid air is vented outdoors. The heat and vent method is simple and effective but it is a great consumer of energy.

The advent of high temperature heat pumps in recent years has led to the introduction of a dehumidification process as a superior method of wood drying. This system is shown in schematic form in Figure 2. Heat pumps are capable of recovering both sensible and latent heat from humid air. The waste stream from a dehumidification kiln is the warm water discharged from the kiln and the heat loss associated with this is significantly smaller than the heat loss associated with the hot humid air stream from the heat and vent kiln. It has been claimed that dehumidification processes save 45 to 60% of the energy used by heat and vent processes/1/.

job	file	date	report no.
740612-684-011	814.35	April 4, 1984	84-59-K

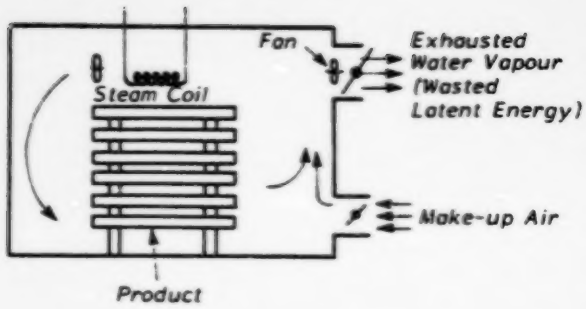

FIGURE 1
HEAT AND VENT

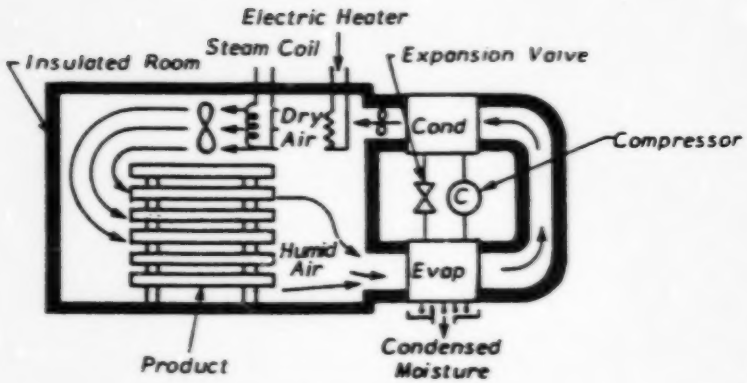

FIGURE 2
DEHUMIDIFICATION HEAT PUMP DRYER

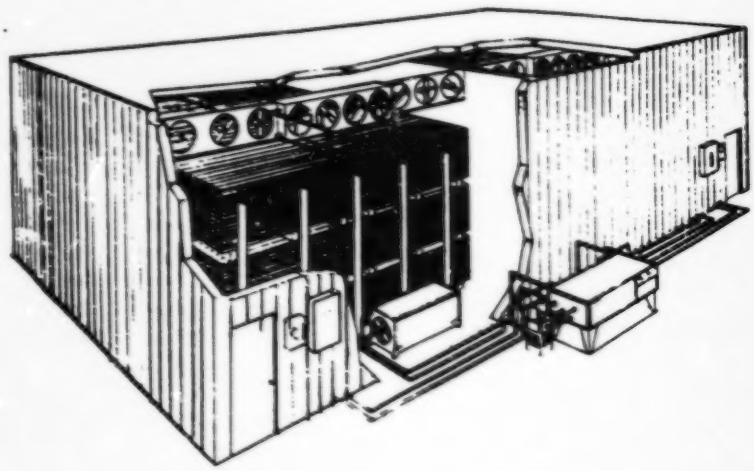

FIGURE 3
HEAT PUMP WOOD KILN

To learn more about the advantages of drying using heat pump dehumidification, and identify potential improvements in dehumidifier performance, a field trial was conducted between September 10, 1982 and March 14, 1983 in a wood kiln (see Figure 3) located at a furniture manufacturing plant in Southern Ontario.

This report summarizes the findings of the field trial and makes recommendations for further work in the field of product drying using dehumidification.

2.0 SUMMARY

Dehumidifier performance was monitored for six drying cycles over a six-month period, September 10, 1982 to March 14, 1983. In addition to the field experiment, manufacturers, kiln owners and other experts were consulted regarding the wood drying process. Summarized below are project results demonstrating that heat pump dehumidification is an attractive load for the electrical utility and such processes can reduce customers' drying costs.

1. Energy saving of dehumidification systems are claimed to be 45% to 60%/1/. Project results have demonstrated savings of 60% for a particular cycle compared to a similar gas heat and vent kiln/1/.

2. Performance Factor was 0.9 kWh per kilogram of water extracted for a cycle. The factor for a similar heat and vent cycle and comparable hardwood would be 2.0 kWh per kilogram of water extracted (Appendix E).

3. The kiln's 42 kW electric heater, operated to boost heat pump output, caused peaks resulting in a load factor of about 30% for the kiln, (Appendix D) which is poor with respect to Ontario Hydro's average load factor of 68%/3/.

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* Mbf denotes 1000 board feet of lumber.
A board foot is a volume 1 foot x 1 foot x 1 inch.

Analysis showed that the heater operated mostly during the day, probably as a result of adjustment of the kiln controls by the operator. Transferring the heater operation to the night would help balance the plant demand thereby eliminating a large part of the demand component of the electric charges with no expected effect on the wood drying process. It is estimated that this would reduce the average cost of electricity for the kiln from 4.0¢/kWh to 3.2¢/kWh.

4. There appear to be advantages to load managing a kiln or group of kilns at the same site. Applying load management was not studied as part of the field trial project. A subsequent in-depth project is recommended.

5. It may be unacceptable to tear down a new heat and vent kiln in order to replace it with a dehumidification system. Retrofitting existing kilns with dehumidifiers may be technically and economically feasible. A subsequent in-depth project is recommended to investigate retrofitting of kilns.

6. A survey of existing wood kilns in Ontario should be conducted to identify ways to encourage dehumidification wood drying technology and determine the size of the potential market.

7. Other commercial and industrial applications of heat pump dehumidification should be investigated. Applications in other countries include drying or curing of plaster products, paper, textiles, clay products etc/4,5,6/.

3.0 DISCUSSION

The following sections present the field measurements and an interpretation of the tested kiln's operation during six drying cycles. Appendix A describes the operation of the kiln.

3.1 Field Measurements

Six wood drying cycles were monitored from September 10, 1982 to March 14, 1983. In all cases hardwoods were dried. Three of the cycles started with wood 'charges' having essentially a saturated moisture content requiring about four weeks of drying time. The other three cycles started with lower moisture contents requiring about two weeks of drying time.

The quantities listed below were continuously monitored and 15 minute averages were recorded.

Heat Pump Electric Input
Heat Pump Thermal Output Energy
Electric Heat
Input to Pumps, Fans, and Auxiliaries
Kiln Dry Bulb Temperature
Kiln Depression Temperature

Quantities were recorded by instrumentation described in Appendix B. Appendix C lists the operating conditions for all six cycles.

A particular cycle was examined in detail and considered to be representative of the performance of this kiln. Conditions for this cycle were:

Drying Cycle:	Oct 6, 1982 - Nov 5, 1982 (30 days)
Wood Charge:	21,320 bf
Moisture Content (% Weight):	Start 60%, End 9%
Total Electric Energy Consumed:	13,343 kWh

3.2 Energy Usage

The main advantage of heat pump dehumidification over the conventional heat and vent method is a large savings in energy consumption. Referring to Figure 4, the net energy requirement of the subject cycle is 626 kWh/Mbf versus an estimated 1650 kWh/Mbf for a comparable heat and vent cycle/1/. The resultant energy savings amounts to about 60%.

Figure 5 illustrates the daily energy consumption during the drying cycle, October 6, 1982 to November 5, 1982. The plot is broken down to three main quantities; 1. heater energy, 2. heat pump energy, and 3. auxiliary (fans, pumps etc) energy.

Auxiliary energy (fans, pumps) is consumed in what may be considered a relatively constant level. The maximum consumption was about 200 kWh/day.

Heat pump energy is also relatively constant except during the start of the cycle (Oct 6 - Oct 12) and at the end (Oct 28 - Nov 6). The heat pump itself functions most effectively when the relative humidity in the kiln chamber is high.

The major contributor to the electrical demand is the 42 kW electric heater which adds a peaky component to the total kiln energy consumption. A closer examination of the hourly kiln

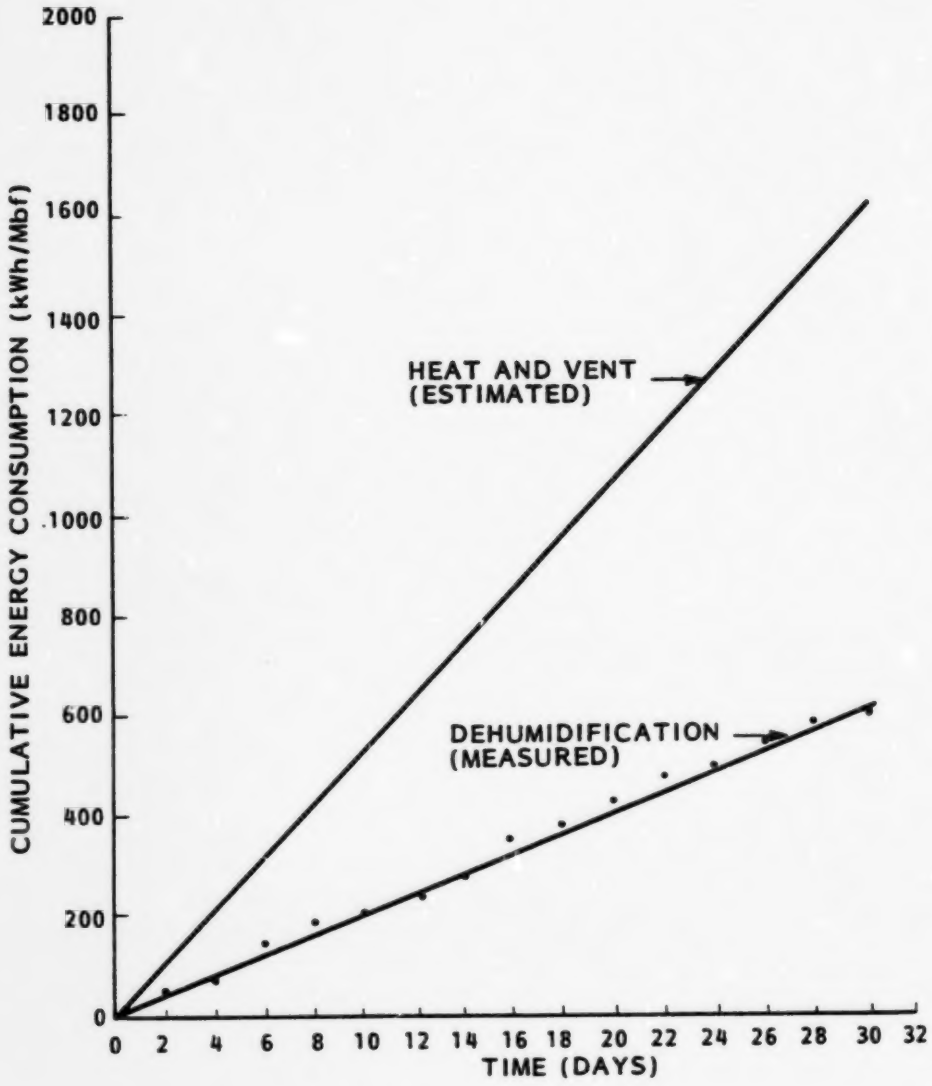

FIGURE 4

NET ENERGY REQUIREMENTS
HEAT/VENT VS DEHUMIDIFICATION WOOD DRYING

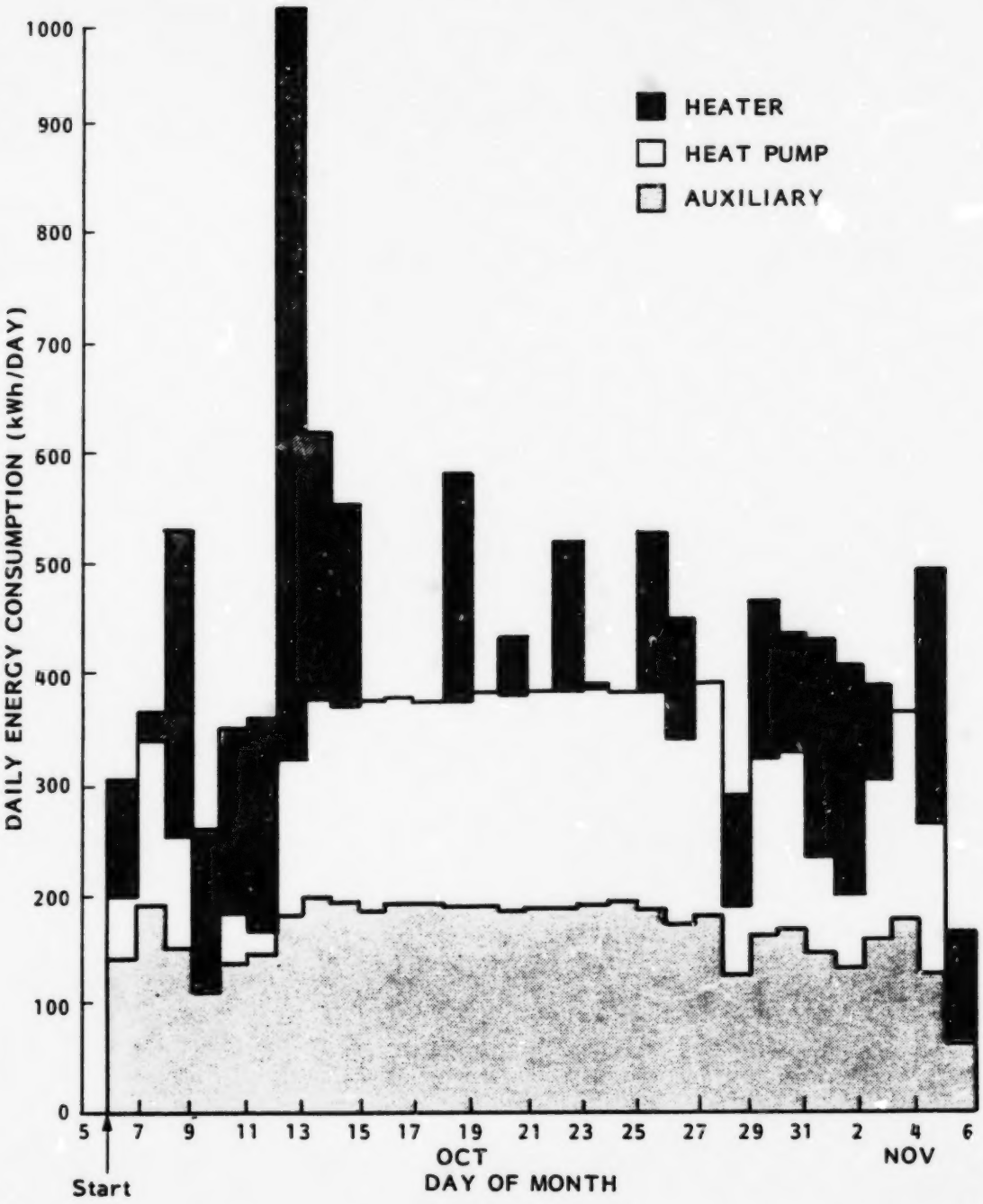

FIGURE 5
DAILY ENERGY CONSUMPTION

load (Appendix D) revealed tnat peaks were concentrated during daytime when electric utilities and customers usually experience demand peaks. Transferring heater operation to off-peak time (night) would benefit the customer since the heater will balance the plant load. In a similar way a group of kiln chambers could be collectively load-managed to prevent coincident heater operation. Since the start of the field trial, the manufacturer of the kiln has begun developing a heat pump wood dryer that incorporates a load management system.

Waste wood from furniture production is burned to generate steam for plant use. Depending on availability, surplus steam is meant to displace electric heater energy. Nonetheless, if the heater operates only once during a billing period, the demand charge will likely be incurred. The demand charge is a significant portion of the electric bill. It has been estimated that for all-electric operation (no steam heat available) elimination of daytime heater operation would reduce the average cost of electricity used by the kiln from 4.0 ¢/kWh to 3.2 ¢/kWh. A controlled, staged electric heater may also help reduce the severity of the problem. Checking the sensitivity of the wood drying process to staged heater operation was beyond the scope of this project.

Total energy consumption during the cycle was 13,343 kWh. Separately the three monitored quantities were:

Heat Pump	=	4,334 kWh	33%
Electric Heater	=	3,912 kWh	29%
Fans, Pumps	=	5,097 kWh	38%
TOTAL		13,343 kWh	100%

Increasing the operation of the heat pump in place of the heater will improve energy savings. This can be accomplished by further reducing the heat loss of the kiln (insulation, sealing etc). Heat and vent operation is often used to boost the moisture removal rate during the beginning of a drying cycle. Maximizing heat pump operation and minimizing heat and vent operation would further improve savings. To do this may increase the initial cost of the installation and a detailed cost-benefit study to determine optimum dehumidifying kiln design requires further investigation.

3.6 Areas for Future Technical Investigation

To exploit the advantages of heat pump dehumidification drying, future study is needed to improve energy savings even more and make the technology more marketable. Sensitivity of the wood to the drying process is a major factor to be considered when undertaking the improvements suggested below.

Load Management and Controls: Load management primarily concerns suppressing demand of the electric heater during utility on-peak times by shifting heater operation to off-peak times or by substituting with an alternate heat source. A simple technique is based on a time clock which inhibits operation of the heater during on-peak time. A more sophisticated technique involves monitoring total plant current and controlling the heater in the following possible manners:

- displace it with surplus steam heat
- displace it using gas or oil (dual fuel retrofit)
- stage the operation of the heater
- delay its operation until night time
- stagger the operation of heaters in a number of kiln chambers.

An effective load management system will lower the average cost of energy to the kiln. Work to define guidelines for such a load management system needs to be undertaken.

Drying Schedules: Dehumidification is a significantly different approach to wood drying than heating and venting. Applying the heat and vent schedule may, for example, under-utilize the heat pump and therefore use more energy than necessary. This may partially explain why only one-third of the total kiln energy was used by the heat pump in the system that was monitored. An investigation is recommended to evaluate and revise existing drying schedules or develop new schedules to emphasize the heat pump and energy efficiency.

Retrofits: The majority of wood dryers at this time are heat and vent systems. Upgrading an existing kiln's thermal envelope and installing an add-on heat pump dehumidifier may be a cheap and cost-effective way of converting existing kilns. A research project is recommended to examine the feasibility of retrofits.

Other Applications: Drying wood by dehumidification has demonstrated that the technology will work and save energy. Drying is widely used in other industries. Work is required to exploit dehumidification drying in other areas such as paper, brick and textile/4,5,6/.

Approved:

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JBC:ljh

REFERENCES

1. Garrahan, P. Some Considerations for Drying Lumber by the Dehumidification Technique. Proceedings of the Saw Milling Clinic. Forintek Canada Corp. Eastern Forestry Products Laboratory. Pub. SP-502E. Ottawa, 1979.

2. Shottafer, J.E. and Shuler, C.E. Estimating Heat Consumption in Kiln Drying Lumber. University of Maine. Technical Bulletin #73, 1974.

3. Ontario Hydro. 1982 Annual Report. Toronto.

4. Booth, B. "Industrial and Commercial Applications of Heat Pumps". Electric Council. London, UK. Paper presented at the "Electro-technologies in Industry Conference". Montreal, Quebec. May 25-27, 1982.

5. Oliver, T.N. "Process Drying with a Dehumidifying Heat Pump". Westair Ltd. UK. Paper presented at the Symposium on "Industrial Application of Heat Pumps". Warwick, UK. March 24-26, 1983.

6. Gauthier, A. and R. Wisshaupt. "Hot Water Preparation and Heating of the Premises at the Metz Abattoir". Paper presented at the Symposium on "Industrial Application of Heat Pumps". Warwick, UK. March 24-26, 1982.

7. Perrott, K. Andrew Malcolm Furniture Company. Correspondence with J.B. Ciz. May 17, 1983.

8. Jessome, A.P. "Strength and Related Properties of Wood Grown in Canada." Forestry Technical Report 21. Ottawa. 1977.

APPENDIX A

KILN OPERATION

DEHUMIDIFICATION HEAT PUMP WOOD DRYER

Listowel, Ontario

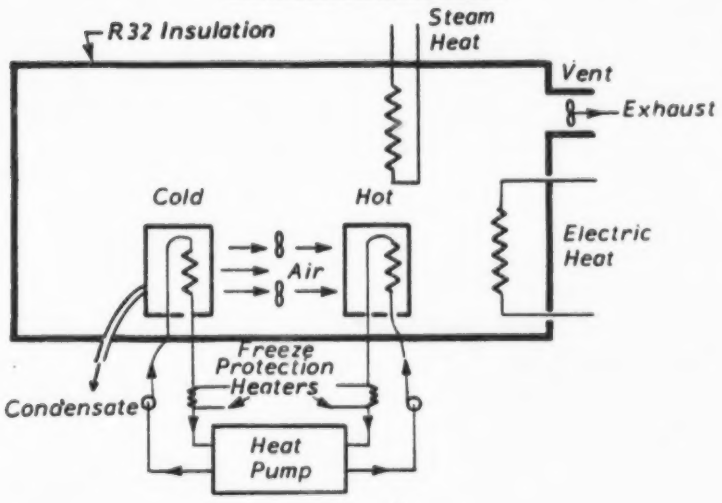

FIGURE 6

HEAT PUMP WOOD DRYER

A heat pump wood dryer removes the moisture from the wood inside the kiln by condensing water vapour on a cold heat exchanger and reheating the resulting dry air with a hot heat exchanger. Other heat sources, usually a steam coil and electric heater, are built-in for preheating the kiln and serve as back-up for the heat pump. When used as backup, the heaters in combination with the vent, perform a heat and vent process. An irregular amount of steam heat is available from burning scrap wood. The electric heater is only operated in the event steam heat is insufficient. Temperature and relative humidity in the kiln are controlled by the system by manually dialed set-points. Wood is dried according to a schedule (a list of set points versus wood moisture content). Different schedules are prescribed for different species of wood.

APPENDIX B

INSTRUMENTATION

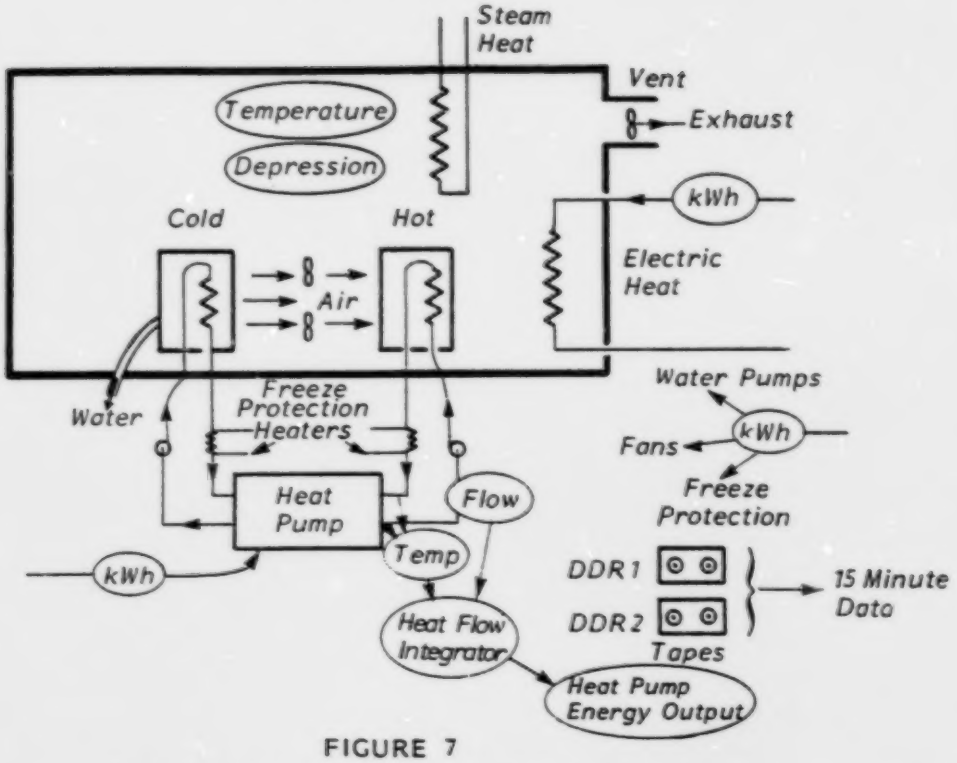

FIGURE 7

HEAT PUMP WOOD DRYER INSTRUMENTATION

Instrumentation was installed in the kiln as shown above. The data below was recorded using digital demand recorders on a 15-minute basis.

Heat Pump Electric Input
Heat Pump Thermal Output
Electric Heat
Input to Pumps, Fans, and Auxiliaries
Kiln Dry Bulb Temperature
Kiln Depression Temperature

To simplify measurements steam heat was disabled between Sept 10, 1982 to Nov 9, 1982.

APPENDIX C

SUMMARY OF OPERATING CONDITIONS

Wood Drying Cycle		Sept 10 - 22/82 12 days	Oct 6 - Nov 5/82 30 days	Nov 9 - Dec 7/82 28 days	Dec 9/82 - Jan 11/83 8 + 8 days (Christmas Shutdown 16 days)**	Jan 19 - Feb 18/83 30 days	Feb 25 - Mar 14/8 17 days
Type of Wood		Hard Maple Cherry	Beech Hard Maple and Ash	Ash Soft Maple	Soft Maple	Soft Maple Hard Maple	Soft Maple
Amount of Wood (bf)		10325 5/4 HM 7050 4/4* C 17375	13005 5/4 B 5075 5/4 HM 2250 6/4 A 21320	6700 6/4 A 11200 5/4 A 4200 4/4 SM 22100	16200 4/4 SM	12110 8/4 SM 2505 10/4 SM 1400 5/4 SM 2610 8/4 HM 1050 5/4 HM 4310 4/4 HM 23985	17850 5/4 SM 4110 6/4 SM 21960
Moisture Content	Start	25%	60%	50%	25%	35%	25%
	Finish	5%	9%	6%	6%	6%	6%
Energy Consumed (kWh)		5868	13343	11774	9016	12437	9355
Steam Heat		Disabled	Disabled	Enabled	Enabled	Enabled	Disabled
Heat Pump COP		3.9 - 5.0	2.6 - 5.2	N/A	N/A	3.6 - 4.3	3.3 - 4.8
Performance Factor*** (kWh/kg H_2O extracted)		1.2	0.86	0.90	2.4**	1.4	1.9

* 4/4 (pronounced 4 quarter) is 1 inch lumber, 5/4 is 1-1/4 inch lumber etc.
** Performance factor was abnormally high because during Christmas a small amount of standby energy was consumed, but no water was extracted.
*** Appendix E

APPENDIX D

SUPPLEMENTARY CURVES

The curves described in the appendix are for the Oct 6/82 - Nov 5/82 drying cycle.

Figures 8, 9, 10 illustrate daily loads for three days, respectively, one day with the heater operating most of the time, the second with the heater not operating, the third with the heater cycling.

The 42 kW heater has a predominant effect on kiln demand. Load Figures 8 and 10 show the heater operates during the day, most likely coinciding with the plant's day shift. Plant steam heat will displace some of the electric heater energy. Nonetheless heater peaks will still occur in winter when steam heat is needed for plant space heating and may not be available for kiln heat.

Kiln total energy consumption is graphed in a different way in Figure 11, Load Duration. The graph shows different minimum kiln demands for a certain number of days during the 30-day cycle. For example, "x" denotes that for two days the kiln demand was at least 30 kW. The sharp peak between two and six days represents the electric heater. Average demand is 17.8 kW. The effective load factor was considered to be:

$$\frac{\text{Average Load}}{\text{Peak Load}} = \frac{17.8 \text{ kW}}{60 \text{ kW}} = 30\%$$

The same cycle showing steam heat completely displacing the electric heater is drawn as Figure 12 indicating absence of the peak. In this case the load factor is improved:

$$\frac{\text{Average Load}}{\text{Peak Load}} = \frac{12.2 \text{ kW}}{18 \text{ kW}} = 68\%$$

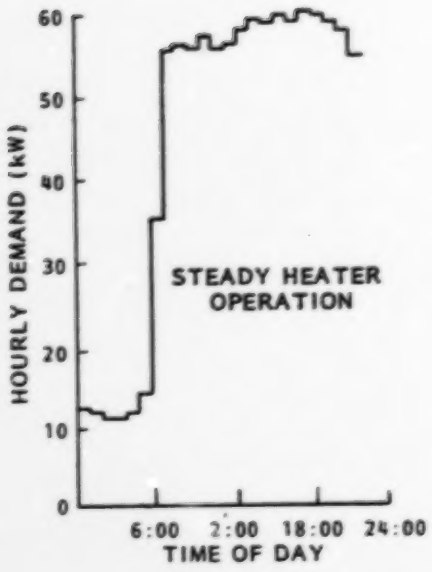

FIGURE 8

LOAD CURVE
OCT 12/82
(Day 6 of a 30-Day Cycle)

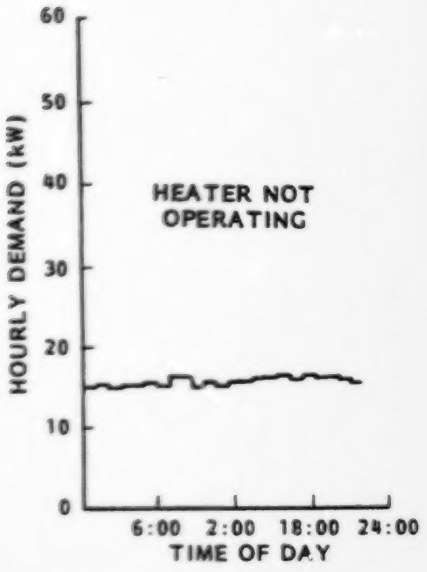

FIGURE 9

LOAD CURVE
OCT 15/82
(Day 9 of a 30-Day Cycle)

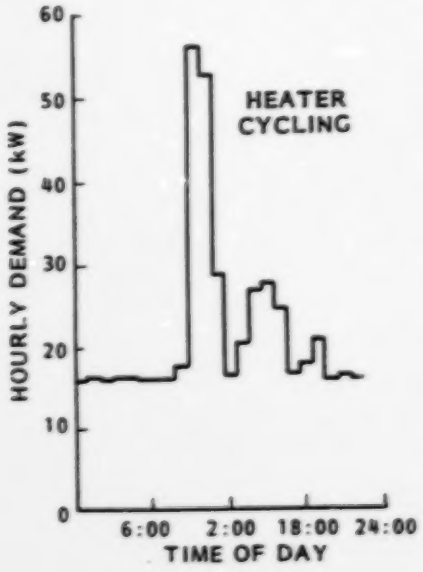

FIGURE 10

LOAD CURVE
OCT 22/82
(Day 12 of a 30-Day Cycle)

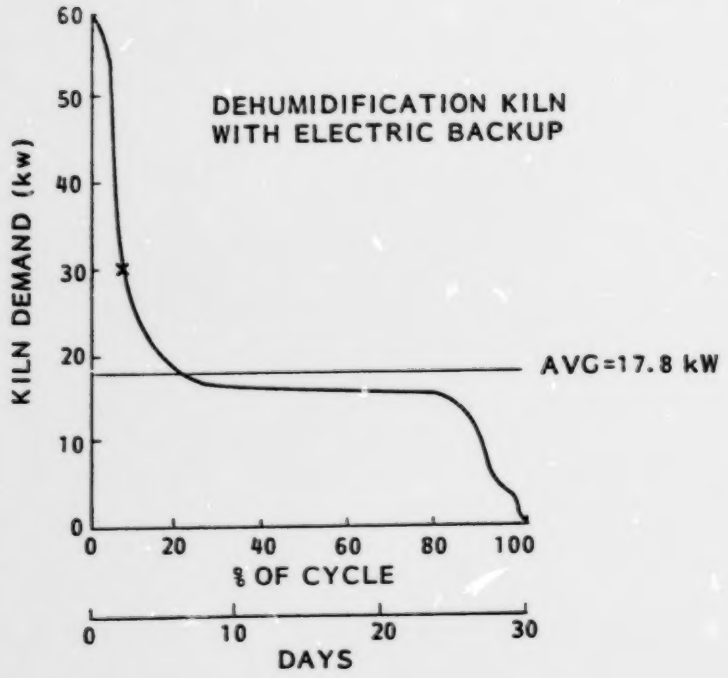

FIGURE 11

LOAD DURATION

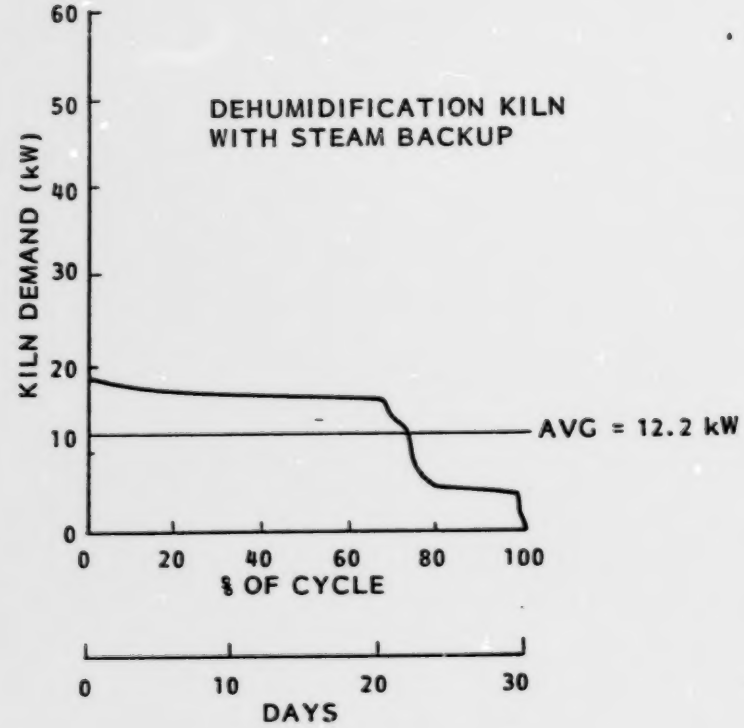

FIGURE 12

LOAD DURATION

APPENDIX E

SAMPLE CALCULATIONS

Performance Factor

This factor is a figure-of-merit and is defined as follows.

$$\text{Performance Factor} = \frac{\text{Total Energy (kWh) Expended to Dry a Wood Charge}}{\text{Weight of Water (kg) Extracted}}$$

Heat Pump Drying Cycle: Oct 6/83 - Nov 5/83

Wood: 13,005 bf of 5/4 beech
5,075 bf of 5/4 hard maple
2,250 bf of 6/4 ash

21,320 Total bf

Total Energy Expended: 13,343 kWh

Start, End Moisture Content: 60%, 9%

Average bone dry density of wood charge, =

$$\underbrace{\frac{13{,}005 \text{ bf}}{21{,}320 \text{ bf}} \times \frac{39.6 \text{ lbs}^*}{\text{ft}^3}}_{\text{5/4 beech}} + \underbrace{\frac{5057 \text{ bf}}{21{,}320 \text{ bf}} \times \frac{40.5 \text{ lb}^*}{\text{ft}^3}}_{\text{5/4 hard maple}} + \underbrace{\frac{2250}{21{,}320} \times \frac{36 \text{ lb}^*}{\text{ft}^3}}_{\text{6/4 ash}}$$

$$= 37.6 \frac{\text{lb}}{\text{ft}^3}$$

$$\text{Weight of water extracted} = 21{,}320 \text{ bf} \times \frac{1\text{ft}^3}{12\text{bf}} \times 37.6 \frac{\text{lb}}{\text{ft}^3} \times \frac{(60\%-9\%)}{100} = 34{,}069 \text{ lb water}$$

or

15,467 kg water

Therefore,

$$\text{Performance Factor} = \frac{13{,}343 \text{ kWh}}{15{,}467 \text{ kg water}} = 0.86 \frac{\text{kWh}}{\text{kg water}}$$

$$= 0.9 \frac{\text{kWh}}{\text{kg water}}$$

* Reference 7, units are in imperial since the industry supplied this data.

Heat and Vent Drying Cycle/1/

Wood: 5/4 northern oak
2 kilns @ 55 Mbf = 110 Mbf (or, 110 000 ft^2)

Specific Gravity: 0.66 (bone dry)*

Total Energy Expended:

$$1650 \frac{kWh}{Mbf}^{**} \times 110 \text{ Mbf} = 182\,000 \text{ kWh}$$

Start, End Moisture Content: 60%, 8%

Weight of Water Extracted:

$$110\,000 \text{ bf} \times \frac{1 \text{ ft}^3}{12 \text{ bf}} \times 0.66 \times 62.2 \frac{\text{lb}}{\text{ft}^3} \times \left(\frac{60\% - 8\%}{100\%} \right)$$

= 200 000 lb water
or
90 800 kg water

Therefore,

$$\text{Performance Factor} = \frac{182\,000 \text{ kWh}}{90\,800 \text{ kg water}} = 2.00 \frac{\text{kWh}}{\text{kg water}}$$

* Reference 8

** Primary energy consumed based on 80% boiler efficiency.

Ontario Hydro

Memorandum To MR. F.J. KEE
Director of Research

Date March 28, 1984

Location or Dept

File 814.35P

Subject Research Report: 84-59-K: Dehumidification Heat Pump Wood Dryer - Performance Evaluation

Attached please find a report analyzing the performance of a wood drying kiln which utilizes an electrically powered industrial heat pump. Performance of the kiln was monitored for 6 months and evaluation confirmed the system saved 60% of the energy used by a comparable fossil-fuelled kiln.

It seems these dehumidification heat pumps are not yet widely used in Ontario industry. Further work is recommended to exploit dehumidification drying in other industrial and commercial areas, such as, paper, brick and textile. The Utilization Section is planning to check the appropriateness of heat pump systems in these areas.

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Attach

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